Altitude-Compensating Nozzle (ACN) Project:

Planning for Dual-Bell Rocket Nozzle Flight Testing on the NASA F-15B

National Aeronautics and Space Administration

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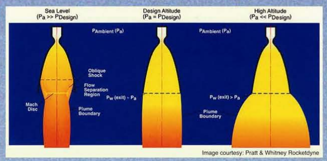
Current Technology: The Conventional-Bell (CB) Nozzle

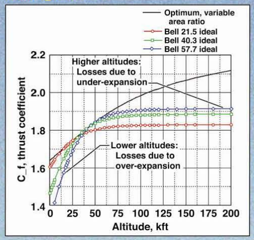
- 1915: The Conventional-Bell rocket nozzle (the de Laval nozzle) was first utilized by Robert Goddard with early rocket experiments
  - Today: The CB nozzle is still the "gold-standard" of all rocket nozzles, and is used on virtually all space-launch rockets
- Problem: The CB nozzle can only be optimized at one altitude
  - Performance losses exist throughout most of a rocket's trajectory



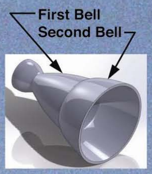
CB nozzle plume behavior during ascent

$$C_f = \frac{F}{P_c A^*}$$

CB nozzle performance during ascent



Proposed Technology: The Dual-Bell (DB) Nozzle

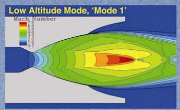


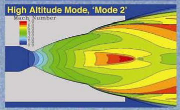
Description

- Several types of Altitude-Compensating Nozzle (ACN) concepts have been studied over the years
- The DB nozzle is one type of ACN, and is predicted to have a higher nozzle efficiency than a CB nozzle
- The DB nozzle has a distinct "Dual-Bell" shape

How it works

- DB 'Mode 1' operation (low altitude):
  - Nozzle flow expands out to the end of the first bell, optimized for lower altitudes
- DB 'Mode 2' operation (high altitude):
  - Nozzle flow expands out to the exit plane, at the end of the second bell
- Goal: The nozzle plume is never significantly over- or under-expanded, as with a CB nozzle, resulting in higher propulsive efficiency





Who Cares?

All space-launch organizations desire higher performing rockets

- This translates into the delivery of higher mass payloads to Low-Earth Orbit (LEO)
- Nozzle performance has a significant effect on a rocket's overall performance
- Decreasing the cost of delivering payloads to LEO has been a vision for NASA and the private sector for several decades

Recently, this national goal has been reiterated within NASA's Launch Propulsion Systems Roadmap (TA01)

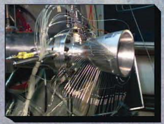
- TA01 emphasizes that "cost-effective access to space is a fundamental capability required for all of NASA's in-space missions"
- TA01 highlights several technology investment areas, one of which is the development and demonstration of advanced nozzle concepts

State of the Art: The Dual-Bell (DB) Nozzle

- 1949: The DB nozzle was first conceived (NASA-JPL)
- 1993: The first DB static-test experiments were published (Rocketdyne)
- Today: Numerous organizations around the world have studied the DB nozzle analytically, continuing to predict greater performance
  - Some organizations have complemented their analytical effort with static test data, to compare against their performance predictions
  - Analytical and experimental research is also being conducted at NASA-Marshall, in the Nozzle Test Facility (NTF)

DB nozzle installed in Marshall NTF

CB nozzle installed in Marshall NTF

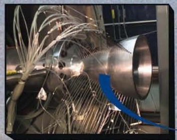


Near-term challenges for DB nozzle researchers:

- Conduct significantly more experimental research with reacting flow
- Conduct nozzle research in a relevant flight environment

The "Big Picture" Plan: Flight Testing the Dual-Bell Nozzle

- Although predicted to be higher performing, the DB nozzle must be proven in a relevant flight environment
- Captive-carry flight testing will enable a more detailed investigation into the nozzle plume behavior and performance at several conditions
  - Captive-carry flight-testing will also enable the propulsion assets to be protected for future testing
- The NASA F-15B Propulsion Flight Test Fixture (PFTF) was developed for captive-carried flight tests with advanced propulsion systems
  - DB nozzle testing can leverage this flight-proven capability



Dual-Bell Flight Test Phases and Top-Level Goals

Phases of the Flight-Test Campaign

- Phase I: Conduct flight tests to survey the freestream flow field conditions near the nozzle exit plane (under the NASA F-15B PFTF)
- Phase II: Conduct flights while operating cold flow through the DB nozzle, as well as with the CB nozzle (for a quantitative comparison)
- Phase III: Conduct flights while operating reacting flow through the DB nozzle, as well as with the CB nozzle (for a quantitative comparison)

Top-Level Goals

- Develop methods to reliably control dual-bell altitude compensation, and demonstrate those methods in a relevant flight environment
- Develop and validate the design and analysis tools required for DB rocket nozzles
- Develop the F-15B PFTF flight testbed and the flight test techniques required for advanced rocket nozzles
- Develop DB performance databases, and databases of flight research with advanced nozzles